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G1G
H4J

(54) Silicon transducer

(57) A transducer which uses a thin silicon strip 1 as its responsive element has a piezo-resistor strain gauge 2 embedded in the silicon near its mounted end. To adjust the resonance characteristics in a desired manner the free end of the silicon element has a small magnet 3, with another magnet 4 in repelling relation therewith. It is also possible to have two magnets, one on each side of the element's free end (Fig. 3, not shown).

In a disc-like transducer (Figs. 5 to 7, not shown), a set of piezo-resistors are located around the disc, with a small magnet at its centre, with one or two magnets adjacent thereto, in the same way as for the strip-like element.

In all cases the magnets near to the silicon can be replaced by electromagnets (Figs. 8, 9, not shown).

The transducer may function as an accelerometer to detect lack of lubrication in bearings, and a scanning accelerometer may be provided by supplying the electromagnets with scanning currents.

In its disc-like form the transducer may function as a microphone or a scanning microphone for use in determining engine characteristics and/or faults.

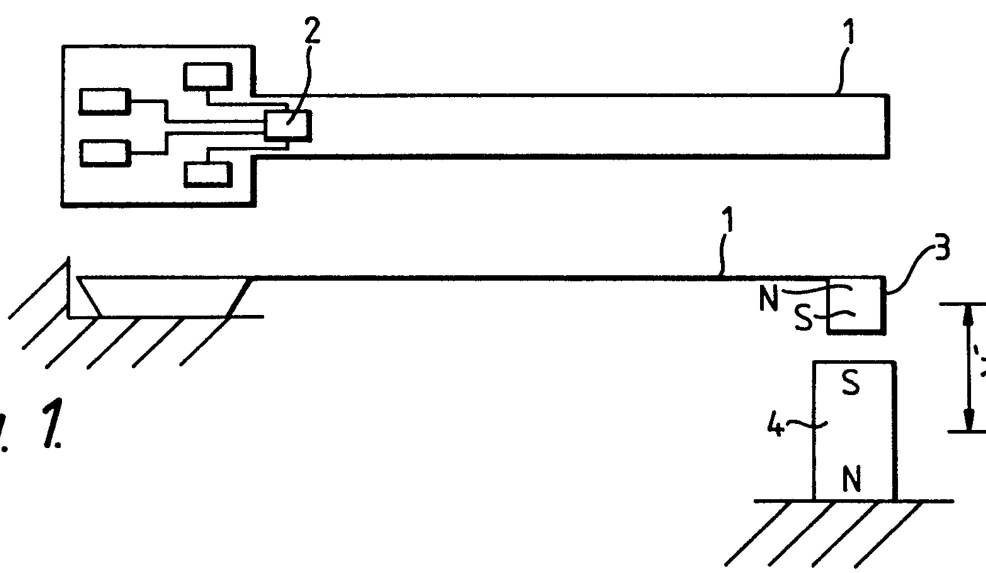

Fig. 1.

The drawing(s) originally filed was/were informal and the print here reproduced is taken from a later filed formal copy.

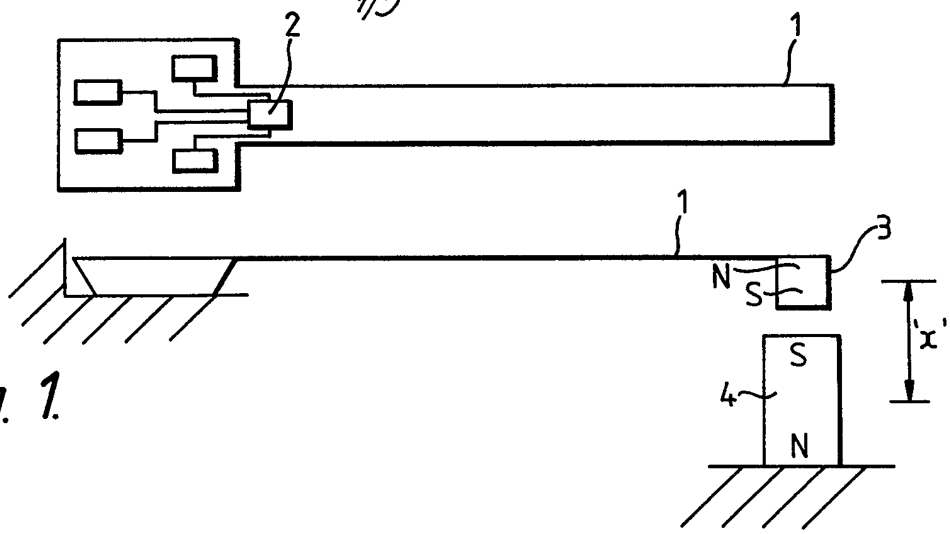

Fig. 1.

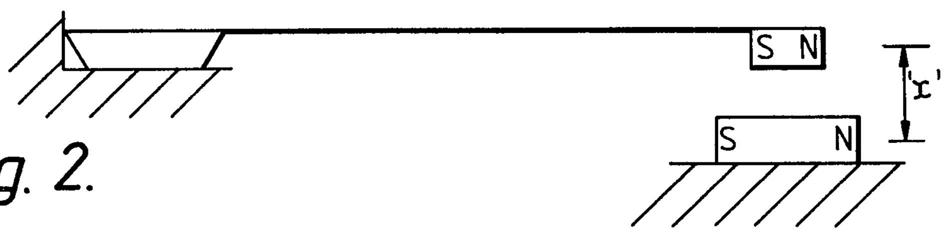

Fig. 2.

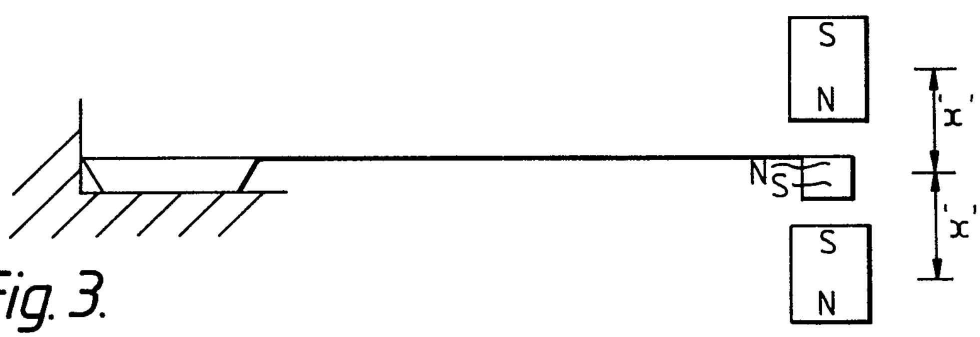

Fig. 3.

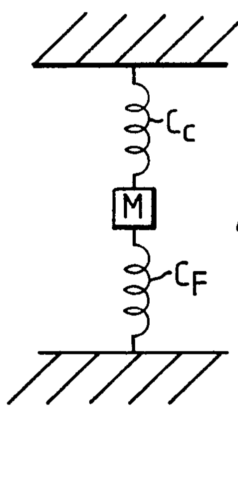

Fig. 4.

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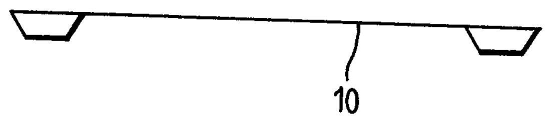
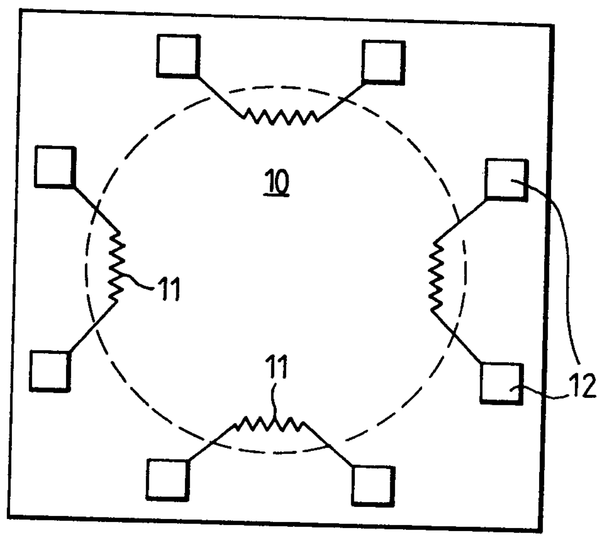


Fig. 5



SILICON TRANSDUCER

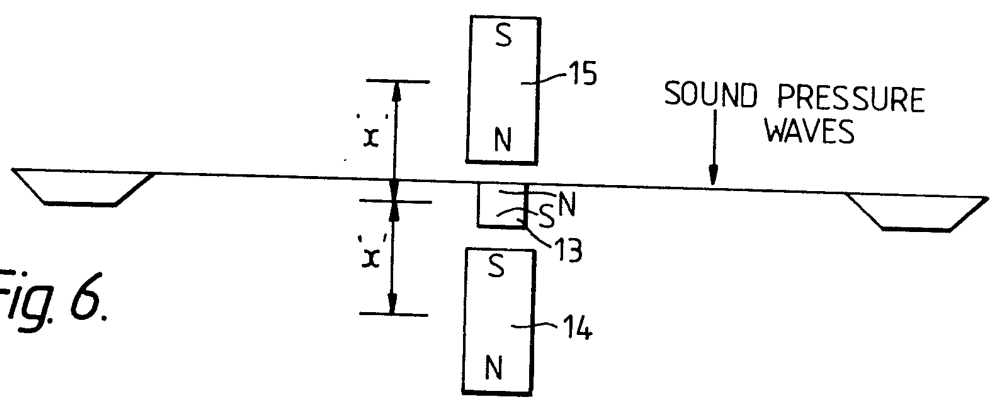


Fig. 6.

Fig. 7.

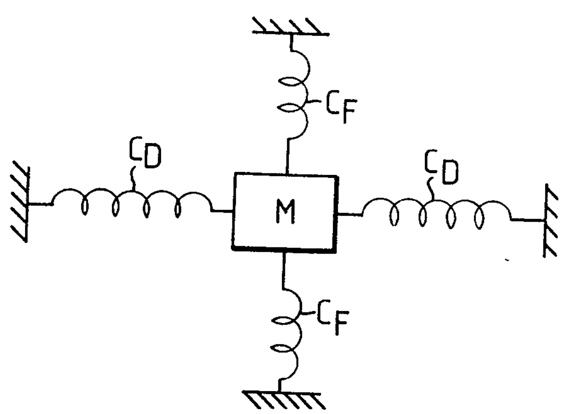


Fig. 8.

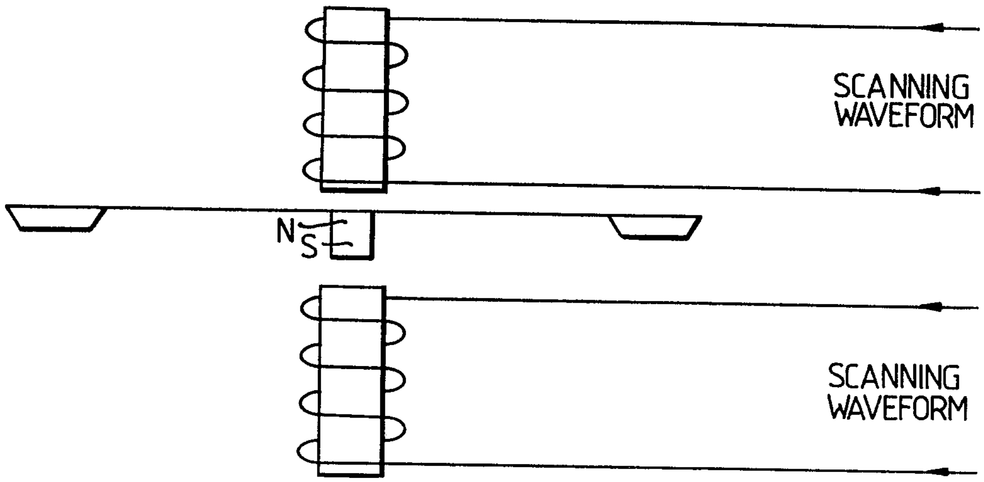
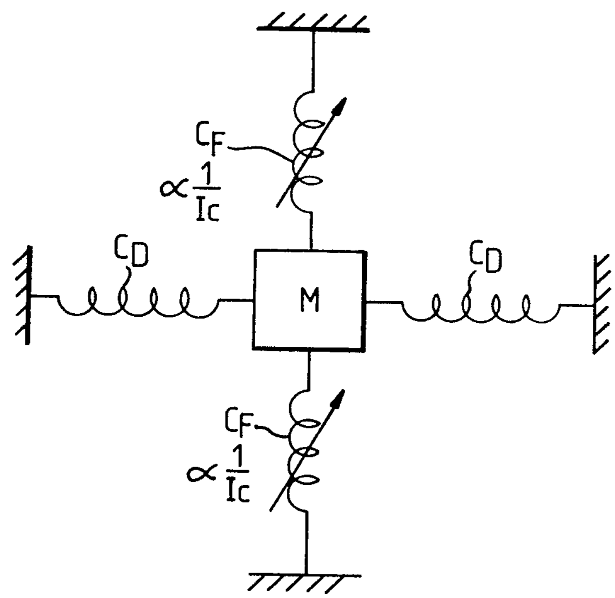

SCANNING
WAVEFORM
N
S
SCANNING
WAVEFORM

Fig. 9.


C_F
$\propto \frac{1}{I_c}$
C_D
M
C_D
C_F
$\propto \frac{1}{I_c}$

SPECIFICATION

Silicon transducer

The present invention relates to transducers of the type in which thin silicon elements are used as the elements responsive to the parameters to be monitored.

According to the invention, there is provided a transducer arrangement, which includes a thin silicon member forming the responsive element which moves in response to a parameter being monitored, strain gauge means associated with the thin silicon element and arranged to give electrical outputs appropriate to movement of the element, at least one permanent magnet mounted on the thin silicon element so as to be movable therewith, and one or more sources of magnetism adjacent to the magnet in the transducer arrangement.

Embodiments of the invention will now be described with reference to the accompanying drawings, in which:

Figures 1, 2 and 3 show schematically transducers in which the silicon element is of strip-like form.

Figure 4 is an equivalent diagram of a transducer such as that shown in Fig. 1.

Figures 5 and 6 show schematically a transducer in which the silicon element, or at least the effective portion thereof, is of circular form.

Figure 7 is an equivalent diagram for the device of Figs. 5 and 6.

Figure 8 is a schematic representation of another transducer.

Figure 9 is an equivalent diagram for the device of Fig. 8.

The silicon transducer shown in Fig. 1, which includes both plan and side views, is a cantilever structure using a thin strip-like silicon element 1. The thin cantilever 1 is normally mechanically deflected to cause a change in strain at the surface in which a piezo-resistive strain gauge 2 is implanted. This strain gauge is connected to a number of contacts, four as shown, on a portion of enlarged area on the silicon element. As shown a small magnet 3 is attached to the end of the cantilever. The resonance frequency of this structure is governed by the compliance of the cantilever and the mass of the cantilever plus the magnet mass. The simple equivalent diagram of Fig. 4 shows the system as the coil spring C_c and the mass M.

If a second permanent magnet 4 is positioned a distance x from the cantilever magnet as shown in Fig. 1, the resonance frequence of the system changes due to the added compliance of the interacting magnetic fields. This is shown in Fig. 4 by the additional spring C_F representing the magnetic field compliance. In the configuration shown with repelling fields, the resonance frequency increases with increasing amplitude of the field.

Fig. 2 shows an alternative orientation of the magnets, and this system behaves in a similar manner to that shown in Fig. 1.

Fig. 3 shows a balanced system in which two permanent magnets are used to provide two repelling fields. This system allows the zero offset of the cantilever to be adjusted out. All of the external magnets shown may be moved to change the distance 'x' and hence the field strength in the gap. The greater the repelling field strength the higher the resonance frequency of the system. Thus, by adjusting the position of the magnet, one can adjust the resonance frequency of the system. If the external magnets are replaced by electromagnets then adjustment of the current through the electromagnet may be used to adjust the system resonance frequency.

Fig. 5 shows another type of thin silicon transducer in which a thin diaphragm 10 has been produced in the silicon. Here the effective area of the diaphragm is substantially circular, and has four piezo-resistors such as 11 on its effective surface, each connected to two contacts such as 12. Such a transducer is usually used as a pressure transducer, the diaphragm deflection being detected in the piezo-resistors which are interconnected to form a balanced bridge. Fig. 6 shows an equivalent system to that shown in Fig. 3 for the cantilever. Here we see the transucer's permanent magnet 13 at the centre of the diaphragm, with two associated permanent magnets 14 and 15. The system responds in a similar manner to that of Fig. 1, reduction of the distance 'x' leading to an increase of the resonance frequency of the system. Fig. 7 is the equivalent diagram for this system, in which the diaphragm is shown by two compliances C_D and a mass M, which comprises the diaphragm mass and the magnet mass. The two additional magnets give rise to two interacting fields which are equivalent to two further compliances C_F. These compliances may be either positive or negative in sense, causing either an increase or decrease in the system resonance frequency. The forces, due to the two external magnets acting on the diaphragm, are equal and opposite, which enables a low zero offset to be achieved.

Note that a transducer such as that of Figs. 5 and 6 could use only one associated magnet, i.e. as in Fig. 1 or 2, and that the associated magnet or magnets can be replaced by electromagnets.

Fig. 8 shows a system in which the permanent magnets have been replaced by two electromagnets. The system resonance frequency is now a function of the current flowing through the coils. This is shown in the equivalent diagram Fig. 9, the compliances C_F being shown as variable elements in which the compliance is inversely proportional to the coil current 'I_c'.

The two forms of transducers described

above may both be used to detect either vibrations through the structure on which they are mounted, or air-borne pressure waves (i.e. sound). In the first instance when detecting mounting structure vibrations the system operates essentially as an accelerometer, with the magnet mounted on the transducer providing the mass. Thus an accelerometer can be provided which can be pre-tuned to provide maximum output at one selected frequency of interest, in which case permanent magnets are used as in Fig. 3 to pre-tune the system.

Alternatively, a scanning accelerometer can be provided in which the permanent magnets are replaced by electromagnets provided with scanning currents. In the same way microphones can be provided which are either pre-tuned to respond to one particular frequency of airborne pressure variations, or to alternatively a band of frequencies can be continuously scanned.

Single frequency detectors find application as low cost devices for continuous checking of bearings where in many cases the generation of a single frequency indicates that the bearing is lacking lubrication. In this case an accelerometer device which would be mounted on the bearing housing is preferred.

To examine the mechanical behaviour of a complete engine, it may be desirable to determine the noise frequency characteristic of an engine using a scanning microphone, in which case the system shown in Fig. 8 is used. Thus the characteristic of "footprint" of the engine when new is compared with the characteristic obtained continuously during the life of the engine in order to determine the onset of an engine fault.

CLAIMS

1. A transducer arrangement, which includes a thin silicon member forming the responsive element which moves in response to a paramenter being monitored, strain gauge means associated with the thin silicon element and arranged to give electrical outputs appropriate to movement of the element, at least one permanent magnet mounted on the thin silicon element so as to be movable therewith, and one or more sources of magnetism adjacent to the magnet in the transducer arrangement.

2. An arrangement as claimed in claim 1, in which the thin silicon member is of strip-like form and secured at one end, in which the strain gauge means is a piezo-resistor on the surface of the silicon member at or near to its secured end, and in which a small permanent magnet is secured at the element's free end.

3. An arrangement as claimed in claim 2, and in which the source of magnetism is a permanent magnet mounted in repelling manner near to the magnet on the free end of the element.

4. An arrangement as claimed in claim 2, and in which the source of magnetism is an electromagnet mounted adjacent to the magnet on the free end of the element.

5. An arrangement as claimed in claim 2, and in which the sources of magnetism are two permanent magnets one near each side of the free end of the element and each in repelling relation with the magnet on said free end.

6. An arrangement as claimed in claim 1, in which the thin silicon element is a disc-like member having a plurality of piezo-resistors spaced about the periphery of the effective area of the element.

7. An arrangement as claimed in claim 6, and in which the magnet on the thin silicon element is located at or near the centre of that element.

8. An arrangement as claimed in claim 7, and in which the source of magnetism is a permanent magnet mounted in repelling manner adjacent to the magnet on said element.

9. An arrangement as claimed in claim 7, and in which the source of magnetism is an electromagnet mounted adjacent to the magnet on the thin silicon element.

10. An arrangement as claimed in claim 7, and in which the sources of magnetism are two permanent magnets each mounted near the magnet on the thin silicon element, each adjacent to that magnet, and each near to a different face of that element.

11. An arrangement as claimed in claim 7, and in which the sources of magnetism are two electromagnets each mounted near the magnet on the thin silicon element, and each near to a different face of the element.

12. A transducing element substantially as described with reference to Fig. 1, Fig. 2, Fig. 3, Figs. 5 and 6, or Fig. 8 of the accompanying drawings.

CLAIMS

Amendments to the claims have been filed, and have the following effect:—

New or textually amended claims have been filed as follows:—

13. A transducer arrangement, which includes a thin silicon member forming the responsive element, which member moves in response to a parameter being monitored, one or more piezo-resistive strain guages implanted into the thin silicon element and arranged to give electrical outputs appropriate to the movement of the element, the or each said strain guage being located at or near the point or points at which the silicon member is secured to its support means, at least one permanent magnet mounted on the thin silicon element, the or each said magnet being at or near to the point of maximum movement of the silicon element, and one or more sources of magnetism adjacent to the magnet or magnet on the silicon element.

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NAME	COUNTRY
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US-CL-CURRENT: 310/311 , 310/330

ABSTRACT:

A transducer which uses a thin silicon strip 1 as its responsive element has a piezo-resistor strain gauge 2 embedded in the silicon near its mounted end. To adjust the resonance characteristics in a desired manner the free end of the silicon element has a small magnet 3, with another magnet 4 in repelling relation therewith. It is also possible to have two magnets, one on each side of the element's free end (Fig. 3, not shown).

In a disc-like transducer (Figs. 5 to 7, not shown), a set of piezo-resistors are located around the disc,

with a small magnet at its centre, with one or two magnets adjacent thereto, in the same way as for the strip-like element.

In all cases the magnets near to the silicon can be replaced by electromagnets (Figs. 8, 9, not shown).

The transducer may function as an accelerometer to detect lack of lubrication in bearings, and a scanning accelerometer may be provided by supplying the electromagnets with scanning currents.

In its disc-like form the transducer may function as a microphone or a scanning microphone for use in determining engine characteristics and/or faults.